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Subject: Geologic Support for Enhanced Gas Recovery via CO₂ Injection at Chestonia 18 Unit

BACKGROUND

The Antrim Shale of northern Michigan is a significant source of natural gas (methane), with gas wells having been drilled and produced since the 1980s. Nearly all of this gas has been produced from within a trend that stretches across the northern part of the state focused mainly in four counties (Antrim, Otsego, Montmorency, and Alpena; see Figure 1). The Antrim shale gas play is notably unique from most shale plays in two ways. First, Antrim gas wells produce the gas from pre-existing natural fractures prevalent throughout the shale, which as a function thereof requires less artificial well stimulation (i.e. high-volume hydrofracking) in order to initiate and sustain gas production. Second, whereas most subsurface natural gas found on earth results from thermogenic processes (heating of the rock, occurring at depths 8000' or greater), gas generated within the Antrim shale is biogenic in origin, resulting from microbial activity within the natural fractures of the shale, and typically occurring at more shallow depths (0' to approximately 3000' below the surface).

Biogenic Gas System

In the Antrim Shale biogenic gas system, microbial activity within the fracture network acts upon the Antrim Shale's carbon rich content to produce methane (CH₄) and carbon dioxide (CO₂). In the hydrostatically pressurized environment within the fracture network, both the newly formed methane and carbon dioxide tend to adsorb or bind themselves onto the fracture walls until such walls are saturated, at which point any remaining methane and carbon dioxide will exist as "free gases" within the fractures. When the system's pressure is reduced the adsorbed methane and carbon dioxide desorb from the fracture walls to join the already available supply of free gas within the system, becoming available for production through the well bore. As such the key to gas production at a typical Antrim Shale well is to lower the hydrostatic pressure in the reservoir by pumping water from the reservoir, and the gas will follow. At the surface, the carbon dioxide is separated from the methane at production facilities and typically vented.

Enhanced Gas Recovery

As carbon dioxide has a higher adsorption potential than methane, the reinjection of carbon dioxide back into the fracture network forces disproportionate saturation of carbon dioxide onto the fracture walls, disproportionately displacing methane from its adsorbed state (on the walls) and rendering it available for production in amounts higher than can be normally achieved using hydrostatic pressure decrease alone (water pumping). Riverside Energy Michigan, LLC proposes an Enhanced Gas Recovery (EGR) pilot project for the Antrim Shale using these principles. In such, continuous injection of carbon dioxide into designated injection wells is intended to increase methane production in surrounding wells.

CHESTONIA 18 UNIT

The Chestonia 18 Unit (the “Project Area”) has been selected as the location for this pilot project and is located in Chestonia Township (T30N-R6W) and Kearney Township (T30N-R7W), Antrim County (Figures 1 and 2). The following review of geologic data evaluates the Antrim Shale within the bounds of the Chestonia 18 Unit, in order to assess the ability of the bedrock column to safely contain, long term, carbon dioxide injected for the purposes of EGR.

Data is taken from 35 wells within the Chestonia 18 Unit (Table 1). In most cases, wireline well logs (gamma ray and neutron density) are available for lithologic and structural analysis, but in several rare cases driller’s reports alone must be referred to for formation tops data. Mud logs are also available and show at what depths gas was encountered during the original drilling of the well. The data has been mapped to show (1) the structure of the Antrim Shale, (2) the thickness of the Antrim Shale, and (3) the thickness of the overburden rock between the top of the Antrim Shale and the base of the unlithified glacial drift (Figures 2-4).

At the Chestonia 18 Unit the Antrim Shale rests on top of the Traverse Formation, an interbedded shaley limestone. The Antrim Shale itself is an organic-rich, carbonate-rich dark shale with high fracture density, and is divided into 3 members: the Norwood, Paxton, and Lachine members (from bottom to top). Directly above the topmost member of the Antrim (Lachine) is the Ellsworth Shale, which is distinct from the Antrim Shale in that the Ellsworth has a much lower total organic content and as such is not capable of gas generation, as well as being more clay-rich in composition and thus less susceptible to natural fracturing. The top of the Ellsworth is erosionally scoured (from during Pleistocene glacial advance) and presently serves as both the top of the local bedrock, as well as the base of the glacial drift. These stratigraphic relationships are depicted via cross-sections in Figures 3 and 4.

At the Chestonia 18 Unit the Antrim Shale averages 136 ft in thickness (Figure 5 and Table 1). The top of the Antrim lies at an average depth of 677 ft from surface (Figure 6). Of importance is the measure of bedrock thickness between the top of the Antrim Shale and the base of the glacial drift (or top of the Ellsworth Shale). This is the vertical interval across which any gases present in the Antrim Shale would have to migrate in order to reach the top of the bedrock column and enter into unlithified glacial drift. At Chestonia 18 Unit this thickness averages 270 ft (min=87, max=386) (see Figure 7). A column of glacial drift (unlithified, albeit compacted sediment) averaging 409 ft (min=195, max 609) in thickness rests directly on the bedrock surface.

Mud logs consistently demonstrate that natural gases in the Antrim interval remain highly confined to the Antrim interval. No evidence of vertical gas migration is present (Figures 8 and 9). Furthermore, carbon dioxide has a higher molecular mass and density (44.01 g/mol) than methane (16.04 g/mol), causing a lesser relative buoyancy. If the local bedrock has successfully confined methane within the Antrim long term, then it can even more so successfully confine additional carbon dioxide at least up to virgin reservoir total pressure. During original drilling these initial pressures were recorded between 228 to 281 psi.

While there are no fracture identification logs from within the Chestonia 18 Unit, fracture identification logs from elsewhere in the Antrim play in northern Michigan typically show a high amount of natural fractures in the Antrim interval, but little to no fracturing in the overlying Ellsworth Shale. Such cases demonstrate what should be expected from the two lithologies: the Antrim’s brittle, carbonate-rich mineralogy, and the Ellsworth’s ductile, clay-rich mineralogy, furthermore supporting the Ellsworth Shale’s quality as an effective confining layer.

GEOHAZARD RISK ASSESSMENT

The Chestonia 18 Unit and surrounding region were evaluated for geohazards. Excellent well control (4.4 wells / square mile) within the Unit provides a high-resolution structural picture of the subsurface and a high-confidence assessment of any potential risk. No known geohazard risks are found to be present.

- Faults – there are no known faults in or near the Antrim and Ellsworth intervals at the Chestonia 18 Unit. Structure mapping on the Antrim Shale (Figure 6) yields no sign of vertical displacement. Nor do any wireline logs within the Unit show signs of any repeat or missing sections (otherwise evidence of faulting).
- Karsts – there are no known karsts in or near the Antrim and Ellsworth intervals at Chestonia 18. Driller's files were reviewed for evidence of bit drops or other details that may suggest karsting is present. No evidence was found.
- Mines – there are no current nor historical surface or underground mines or mining activity in this part of Michigan.
- Lost Circulation – While there is occasionally lost circulation in the Traverse Formation and Traverse Limestone (both below the Antrim) lost circulation zones in or above the Antrim Shale are uncommon and no evidence for such has been discovered from wells files at the Chestonia 18.
- Competency or induced seismicity problems – There is presently no industrial scale/nature of activity in the Project Area other than the daily production operations of the natural gas wells themselves. Regularized volumes of water produced from the Antrim as a byproduct of gas production are gathered at centralized injection well locations for continuous injection into the Dundee Limestone, at a depth of 1650 ft. The Dundee itself is confined below 100 ft of Bell Shale. This water disposal process has been ongoing since 1994 and the Dundee accepts water on a vacuum. As this is a long-standing practice operating at low pressure, there are no mechanical risks of anthropogenically induced seismicity from this or any other current nearby activity.

RECOMMENDATION

It is herein recommended that a volume of carbon dioxide equal to at least the total volume of all gases historically produced from the Project Area, can be safely reinjected long-term into the Antrim Shale interval at Chestonia 18 for the purposes of EGR, without consequence of leakage through the subsurface and to the surface. Mud logs from wells drilled at and around Chestonia 18 Unit, as well as throughout the entire Antrim Shale play demonstrate a high level of confinement of gas phases within the Antrim's fracture network. Even where natural fractures are present in the overlying Ellsworth Shale, gas measurement logs show a very clear transition between the gas-rich Antrim and a gas-free Ellsworth. The absence of methane gas seeps at the surface in northern Michigan indicates that virgin pressures in the Antrim reservoir were sufficiently low enough to allow gas phases internal to the fracture network to remain confined to the Antrim interval.

Since inception, the Chestonia 18 Unit has produced 8,402,546 Mcf of gases (methane and carbon dioxide). The proposed carbon dioxide EGR project aims to inject up to 450 Mcf of carbon dioxide per day for up to 20 years, or a total of 3,285,000 Mcf. This volume is well below the volume of gases formerly produced from the Unit and as such poses no apparent risk to breaching the confinement of the Antrim-Ellsworth contact horizon nor reaching the surface in any other capacity.

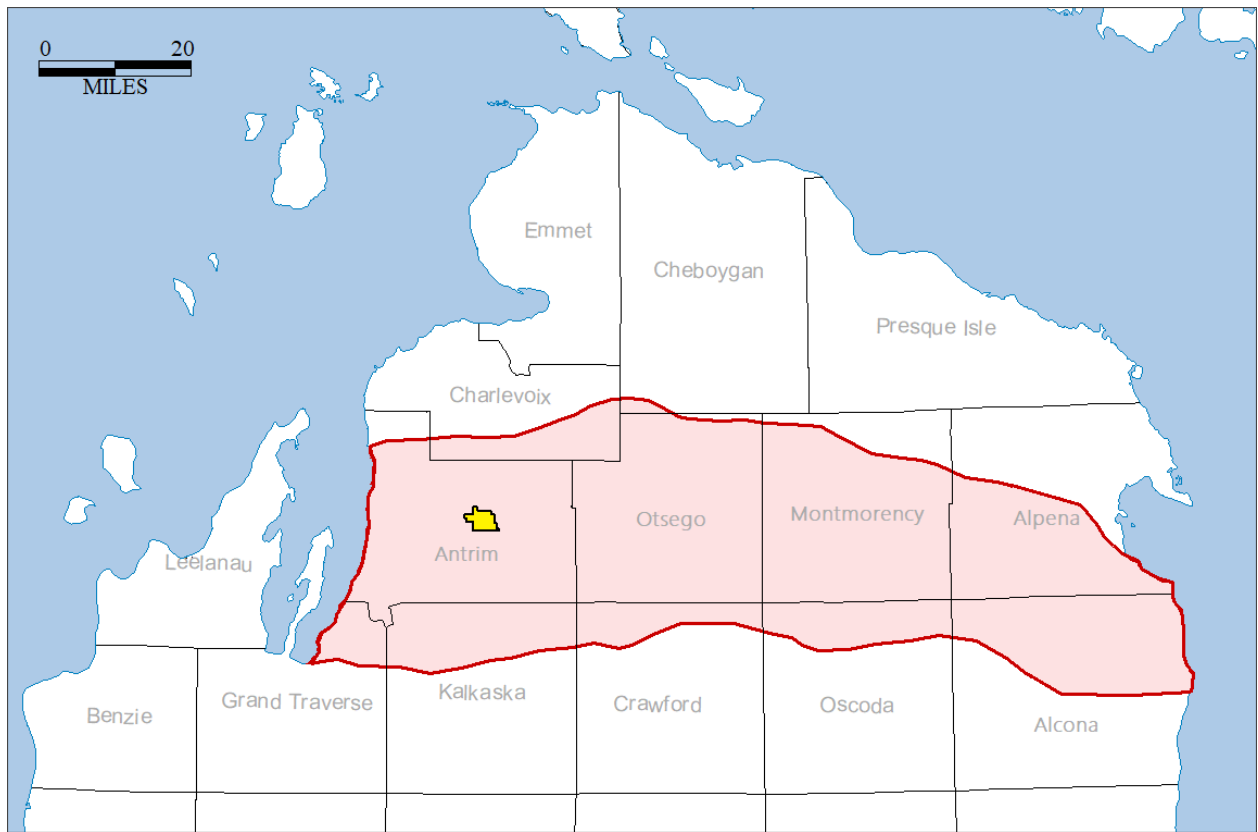


Figure 1. County map of northern Lower Peninsula, Michigan, showing the main developed extent of the Antrim Shale gas play (red), and the Chestonia 18 Unit (yellow) whereat Riverside Energy Michigan, LLC herein proposes a carbon dioxide based Enhanced Gas Recovery project.

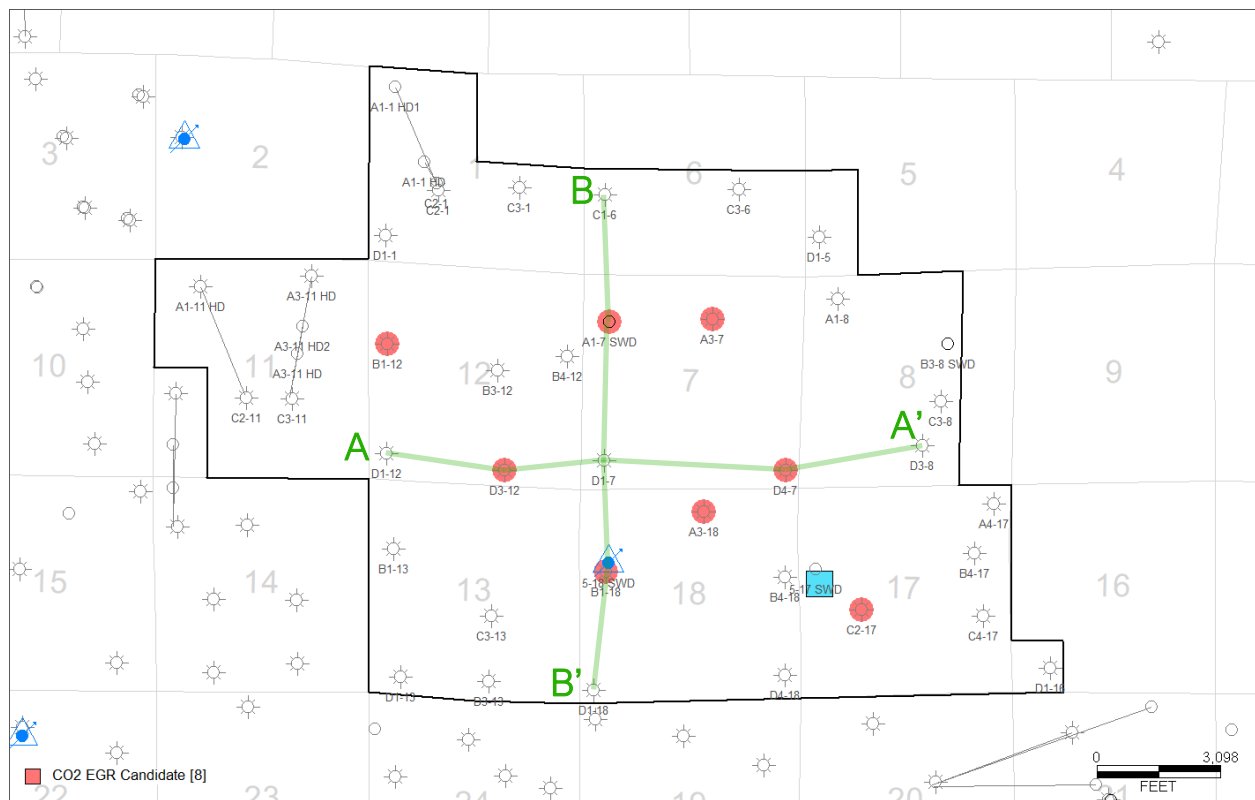


Figure 2. Base map of the Chestonia 18 Unit, showing the unit boundary outline (black), candidate wells for carbon dioxide injection (red), the Chestonia carbon dioxide processing plant (blue), and locations of two geologic cross-sections (green, A-A' and B-B', see figures 3 and 4).

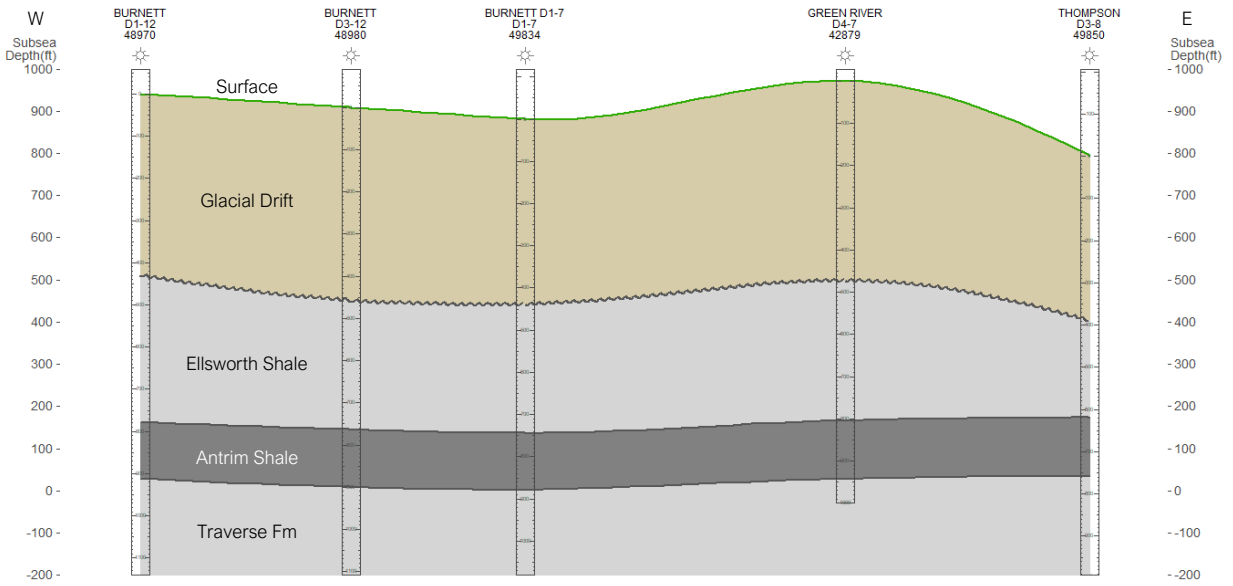


Figure 3. East-west cross-section (A-A') of the Antrim Shale and overlaying strata at the Chestonia 18 Unit.

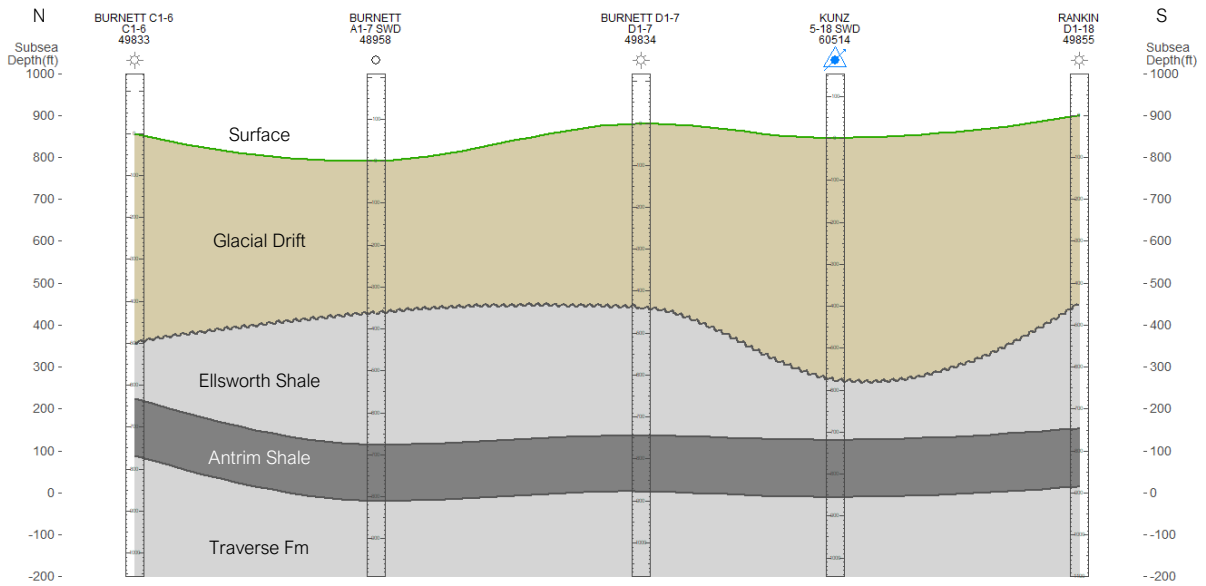


Figure 4. North-south cross-section (B-B') of the Antrim Shale and overlaying strata at the Chestonia 18 Unit.

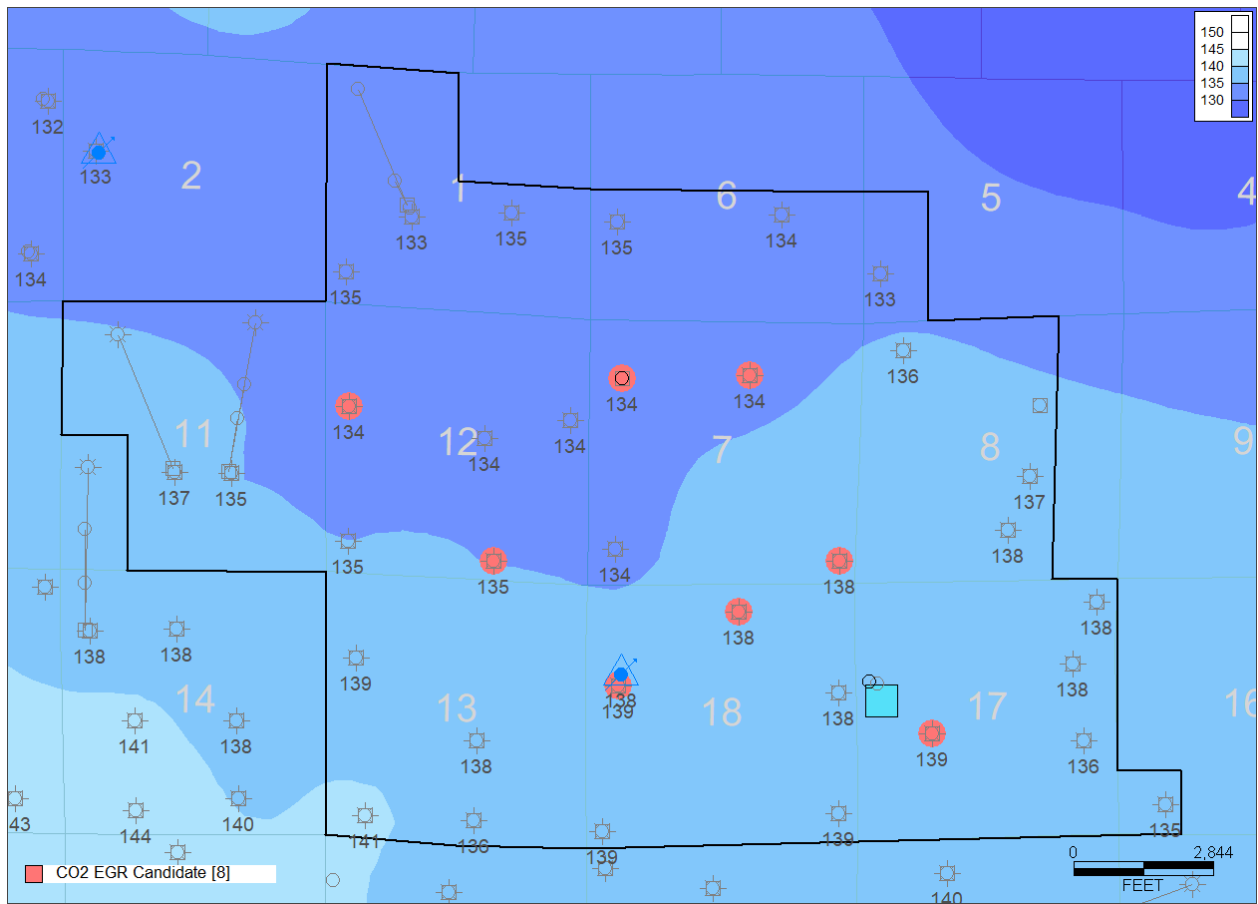


Figure 5. Chestonia 18 Unit - Isopach thickness map of the Antrim Shale (C.I. = 5 ft). Structure data determined from well logs and driller's reports are posted at well symbols. Also shown are candidate wells for carbon dioxide EGR injection (red), and the Chestonia 18 carbon dioxide processing facility (blue square). Note the consistency of regional Antrim thickness across the Unit boundaries.

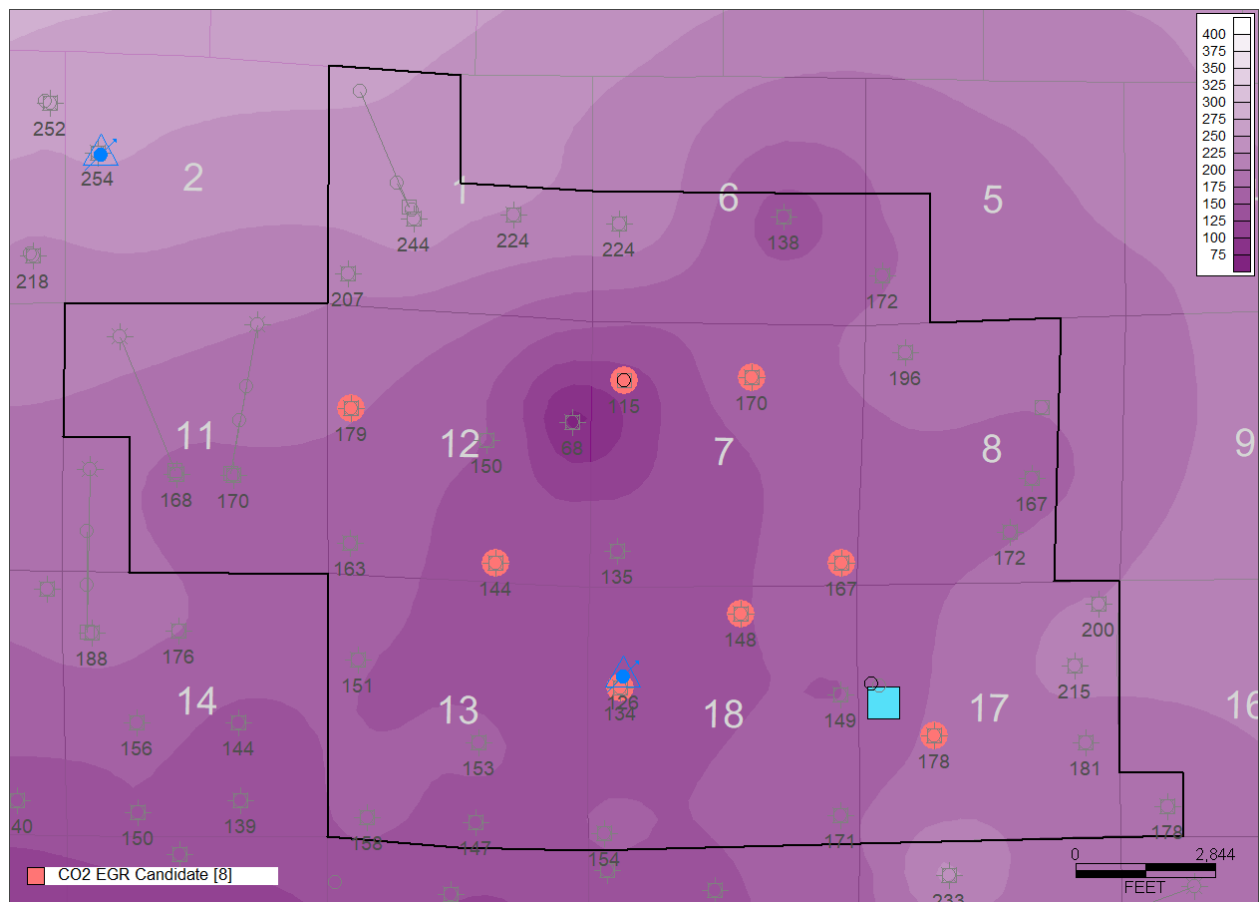


Figure 6. Chestonia 18 Unit - Structure map of the top of the Antrim Shale (C.I. = 25 ft). Structure data determined from well logs and driller's reports are posted at well symbols. Also shown are candidate wells for carbon dioxide EGR injection (red), and the Chestonia 18 carbon dioxide processing facility (blue).

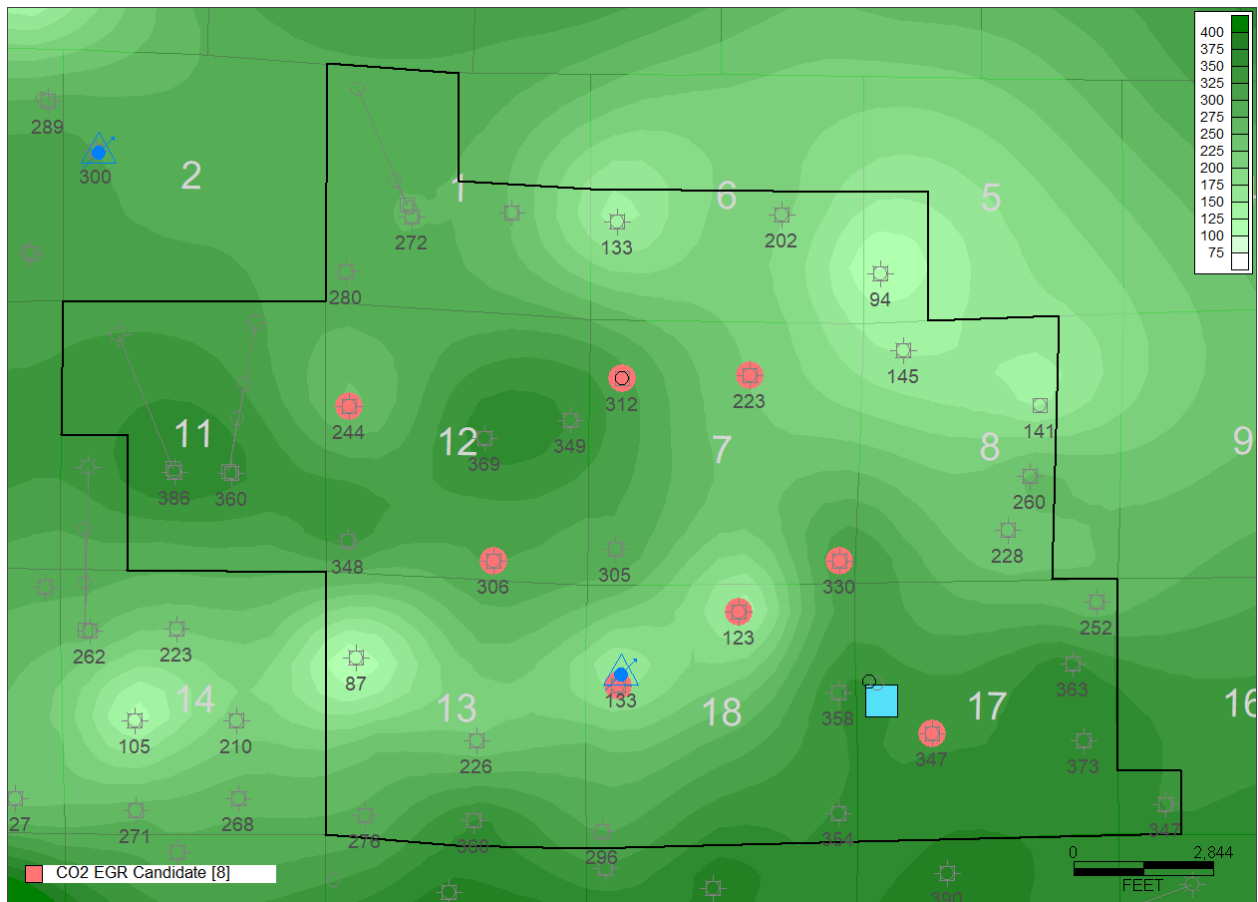


Figure 7. Chestonia 18 Unit - Isopach thickness map (C.I. = 25 ft) showing thickness of bedrock stratigraphy between the top of the Antrim Shale and the base of unlithified glacial drift. Thickness data calculated from well logs and driller's reports are posted at well symbols. Also shown are candidate wells for carbon dioxide EGR injection (red), and the Chestonia 18 carbon dioxide processing facility (blue).



275 Units Gas

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Table 1. Chestonia 18 Unit well data from 36 wells with complete tops information. All top and base values displayed as measured depth, surface displayed as ft above sea level, and isopach values displayed as thicknesses.

API	Well	No.	Surface	Glacial Till Base /or Ellsworth Top	Glacial Till Isopach	Ellsworth Isopach	Antrim Top	Antrim Base	Antrim Isopach
21009487310000	BURNETT	D1-5	692	426	426	94	520	652	133
21009487830000	BURNETT	A1-8	732	390	390	145	536	671	136
21009489580000	BURNETT	A1-7	791	364	364	312	676	810	134
21009489700000	BURNETT	D1-12	941	430	430	348	778	913	135
21009489780000	BURNETT	C3-6	684	344	344	202	546	680	134
21009489790000	BURNETT	A3-7	859	467	467	223	689	823	134
21009489800000	BURNETT	D3-12	909	459	459	306	765	900	135
21009498330000	BURNETT	C1-6	857	500	500	133	633	768	135
21009498340000	BURNETT	D1-7	881	441	441	305	746	880	134
21009558130000	BURNETT	A3-18	881	609	609	123	733	871	138
21009498540000	CUCA	C3-8	834	410	410	260	667	804	137
21009558110000	DAVIS	C2-17	830	305	305	347	652	791	139
21009503790000	DEVREISE	B3-8	711	421	421	141	519	653	134
21009428790000	GREEN RIVER	D4-7	971	474	474	330	804	942	138
21009504020000	GUSTAV	D1-13	834	400	400	276	676	816	141
21009489810000	KAFI	B4-12	783	367	367	349	715	849	134
21009498350000	KAFI	C3-1	817	NA	NA	NA	593	728	135
21009498360000	KAFI	D1-1	696	209	209	280	489	624	135
21009498370000	KAFI	B1-12	806	383	383	244	627	761	134
21009506650000	KAFI	C2-1	711	195	195	272	467	600	133
21009558120000	KAFI	B3-12	800	281	281	369	650	784	134
21009498570000	KLADZYK	D3-13	892	385	385	360	745	881	136
21009558100000	KLADZYK	C3-13	846	467	467	226	693	831	138
21009489720000	KOTZ	C2-11	908	400	400	386	740	877	137
21009489710000	KOUTNIK	B1-13	846	608	608	87	695	834	139
21009487820000	KUNZ	B4-18	867	444	444	358	718	856	138
21009488780000	KUNZ	B1-18	838	555	555	140	704	843	139
21009605140000	KUNZ	5-18	845	576	576	133	719	857	138
21009487320000	MOORE	C3-11	881	351	351	360	711	846	135
21009498550000	RANKIN	D1-18	900	450	450	296	746	885	139
21009498580000	RITT	D1-16	922	397	397	347	744	879	135
21009498560000	STALL	D4-18	867	341	341	354	696	835	139
21009498500000	THOMPSON	D3-8	793	392	392	228	621	759	138
21009498510000	URBAN	C4-17	892	339	339	373	711	847	136
21009498520000	URBAN	B4-17	1,013	435	435	363	798	935	138
21009498530000	WRIGHT	A4-17	900	448	448	252	700	837	138